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Development Strategy of Key Materials for Information Display in China

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Abstract: As the fourth industrial revolution led by intelligence continues, the information display industry, which is the carrier of information interaction, has become a primary industry for new-generation information technologies. China's display industry is the world's largest in scale; however, some developmental barriers are emerging, such as deficiencies in upstream key materials that limit its overall development. Therefore, an improvement is required in the independent and controllable ability of the industry chain and supply chain of display materials in China. This study analyzes the development status of key materials for information display industries in China and abroad and focuses on the core technologies, raw material self-supply capability, and industrialization development of key materials. It also summarizes the shortcomings and major challenges in the development of key materials for information displays in China and proposes key material development goals, industrial development paths, and technology breakthrough paths. To promote the display material industry, we propose: (1) establishing new research and development platforms for national information display materials and strengthening the leadership of national technological forces; (2) improving the layout of major special projects for information display materials and strengthening the construction of a material technology system; (3) cultivating world-class enterprises with global competitiveness and strengthening the ecological leadership of the industrial and supply chains; and (4) deepening multi-chain integration and further cultivating industrial ecology through an industrial collaboration platform.
Keywords: information display; key materials for information display; autonomous and controllable; industrial chain; supply chain

1 Introduction

Information displays form an important part of the electronic information industry. With the ongoing digital transformation globally and the increasing information display downstream demand, such as consumer electronics and industrial digitalization, the information display industry has become critical for countries worldwide to upgrade information consumption and boost their digital economies.

Presently, several display technologies have emerged worldwide and are exhibiting rapid growth, resulting in a positive cycle for industrial development. In 2020, the output value of the global information display industry exceeded 300 billion USD. Mainstream technologies such as thin-film transistor liquid crystal displays (TFT-LCDs) [1] and vapor-deposited organic luminescent diode (OLED) displays [2] are constantly being upgraded. Novel technologies such as printing OLED displays, quantum dot displays [3], laser displays [4], and mini/micro-LEDs [5,6] are maturing, and ongoing breakthroughs in the development of cutting-edge technologies such as light-field displays and nano-LEDs are being reported. Research and application of display technologies will be

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further expanded as they span many other disciplines such as material, semiconductor, and information technologies.

Recently, materials that are key to China's information display industry have undergone major advancements. As the industry continues to expand and merge, it has attained a leading position. In 2020, the cumulative investment of the whole industry in mainland China was 1.24 trillion CNY, with a 65-billion-USD output value and a 446-billion-CNY direct revenue, as well as a year-on-year increase of 19.7%. Its global market share reached 40.3%, ranking it first in the world [7]. In the midstream of the industrial chain, China's display panel shipment accounts for more than 50% of the total worldwide. The world's highest-generation LCD panel production lines, namely, the 10.5th generation lines of BOE Technology Group Co., Ltd. and the 11th generation lines of TCL China Star Optoelectronics Technology Co., Ltd. in Wuhan, have achieved full production and full sales. BOE's fully flexible active-matrix organic luminescent diode (AMOLED) panel production line in Chengdu is already achieving mass production. China has become the main producer and exporter of display terminals (e.g., TVs, computers, and mobile phones), accounting for over 50% of the global market.

China's mid- and downstream sectors of the industrial chain, such as information display panels and consumer electronics, are developing, while the weakness of upstream materials is simultaneously becoming prominent. Compared with developed countries, more than 60% of the key materials cannot be independently supplied, and a significant risk of bottlenecks exists in some fields, posing a major threat to China's information display industry.

To overcome this weakness, Chinese researchers have carried out a significant amount of research and analysis on the shortcomings mentioned above. Xu Zuyan et al. [8] explained the current status of some display materials and analyzed issues related to China's display materials from the perspective of market competition; Jiang Hong et al. [9] conducted detailed research and analysis on OLED technology and application progress; and Gong Xueyuan et al. [10] studied the present situation of quantum dot material industrialization and discussed the upcoming challenges and opportunities.

Research in the above fields provides important guidance for China's display materials, but research on cutting-edge display technology, forward-looking key materials, industry constraints, and key technology development paths has not been discussed. Thus, this study investigated in detail the four key display materials, namely functional materials, glass materials, kitting materials, and flexible polymer materials. Based on development status and demand analysis, the degree of autonomy and the latest achievements of China's key display materials are summarized. Moreover, the research status of forward-looking materials is reviewed, and the constraints analyzed. Industry development paths are designed, and specific proposals are made to promote the completion of China's key information display material chain.

2 International development status and trend

2.1 Development status

The key materials for information display can be mainly divided into four categories: functional materials, glass materials, kitting materials and flexible polymer materials, including liquid crystal materials, OLED light-emitting materials, glass substrate, flexible glass, photomask, photoresist, and polyimide film (PI). Owing to the deep combination of display materials, technologies, and applications, the national display technology innovation capacity and production scale and market have become key factors that motivate upgrades to these materials. The USA, Europe, Japan, and Korea are currently in the first tier, followed by China and India.

2.1.1 Functional materials

Display functional materials mainly include liquid crystal material and OLED luminescent material.

High-performance hybrid liquid crystal material, which is made from a variety of monomer liquid crystals, is the core of LCD panels. The technical barrier is high owing to the extremely difficult synthesis process. The Merck Group in Germany and the JNC Group and DIC Corporation in Japan account for 50% of its global market share, wherein the Merck Group is in an absolute leading position.

OLED luminescent material is core for OLED devices. The core patents for these materials are owned by LG Chem in South Korea, Idemitsu Kosan in Japan, Merck Group in Germany, and Universal Display Corportion in the USA. Meanwhile, vapor deposition equipment is monopolized by Canon Tokki in Japan, and Sunic System and SFA Engineering Corporation in South Korea.

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2.1.2 Glass materials

Display glass [11] is one of the key basic materials for the information display industry, and mainly includes TFT-LCD glass substrates, OLED glass substrates, low-temperature polysilicon (LTPS) glass substrates, cover glass, and flexible glass [12].

TFT-LCD glass substrate and OLED glass substrate are crucial to the production of LCD and OLED devices, respectively. At present, glass substrate products from the 8.5th generation and above are dominating the market, and the key technology is possessed by Corning Incorporated in the USA and the AGC Group and Nippon Electric Glass Co., Ltd. (NEG) in Japan. These three companies occupy more than 90% of the global LCD/OLED glass substrate market share.

LTPS glass substrates can be used as OLED carrier glass. With a high technological standard, more than 90% of the global market is controlled by Corning and AGC.

Cover glass is used to support and protect the display panel because of its characteristics, such as high hardness, scratch resistance, and anti-fingerprint quality. High-end cover glass market shares of Corning, AGC, Schott Group in Germany, and NEG are 60%, 15%, 10%, and 5%, respectively.

In recent years, the emergence of flexible glass has supported the application of foldable terminals and led to a new trend of consumer electronics. Some companies (i.e., Corning, Schott, AGC, and NEG) have successively developed a series of flexible glass products, whereas the one-step molding technology is still in development (Table 1).

Table 1. Major flexible glass manufacturers and products.

Companies	Product	Thickness (μm)	Glass constituents
Corning	Willow glass	100	Alkali-free aluminosilicate glass
Schott	AF32®eco	25–100	Boroaluminosilicate glass
	D263®Teco	70–250	Borosilicate glass
	Xensation®Flex	~70	Lithium aluminosilicate glass
AGC	Spool	40–50	Soda-lime silicate glass
NEG	G-Leaf	30	Alkali aluminosilicate glass

2.1.3 Kitting materials

Display kitting materials include targets, photoresists, photomasks, optical films, and polarizers.

The advanced fabrication technique of the target material has been mastered by only a few companies, namely, the Plansee Group in Austria; the Starco Group and Heraeus Group in Germany; and the Ulvac Group, Sumitomo Chemical Co., Ltd., and JX Nippon Mining & Metal Co., Ltd. In Japan. Among the various target materials, molybdenum target suppliers mainly include Plansee and Starco; most of the aluminum target material market is occupied by Sumitomo and Ulvac; indium tin oxide (ITO) target material is supplied by JX, Mitsui Mining & Smelting Co., Ltd., and Umicore Co., Ltd. in Belgium; and copper target is mainly from Ulvac and JX.

Photoresists mainly include color photoresist, black photoresist, TFT positive photoresist, and photoresist for touch screens, and Merck, Tokyo Ohka Kogyo Co., Ltd., JSR Corporation, Sumitomo, and Dongjin Semichem Co., Ltd. are the major suppliers. Among them, Merck is the world's largest TFT positive photoresist product supplier. Seven companies, namely JSR, LG Chem, Samsung Chemical Industry Co., Ltd., Toyo Ink Group, Sumitomo, Chimei Corporation in Taiwan, China, and Mitsubishi Chemical Corporation, account for more than 83% of the global color photoresist production. The main manufacturers of black photoresist, with a higher concentration, are Ohka Kogyo, Samsung, Nippon Steel & Sumikin Chemical Co., Ltd., Mitsubishi, etc. Developed countries monopolize the production of resin materials, which is the key constituent of photoresists.

The main TFT-LCD photomask manufacturers, Hoya Group, SKE Co., Ltd., and Dai Nippon Printing Group (DNP) in Japan, and LG Electronics Co., Ltd. in South Korea, are dominating the market for 8.5th-generation-and-above products. The fine metal mask (FMM) for AMOLED is difficult to manufacture and is monopolized by DNP, Toppan Inc. in Japan, and Photronics Inc. in South Korea. The key raw material is ultra-thin Invar (10–20 μm) and is produced by Hitachi Metals, Ltd (in Japan) only.

Most polarizers are supplied by companies in China, Japan, and South Korea. For example, Shanjin Optoelectronics Co., Ltd. in China, Sumitomo, Samsung SDI Co., Ltd., and Nitto Denko Corporation in Japan, respectively, own 25%, 22%, 12%, and 9% of the market. However, triacetate (TAC) film and polyvinyl alcohol (PVA) base film, the raw materials of polarizers, are monopolized by Japanese companies, with Fuji Co., Ltd. accounting for 53% of the TAC film market, while Kuraray Co., Ltd. supplies 80% of the PVA film worldwide.

2.1.4 Flexible polymer materials

Flexible polymer materials include flexible base polymer material, adhesive polymer material, and photosensitive holographic recording polymer material.

Flexible OLED devices employ PI paste, which is supplied by a few companies such as DuPont in the USA and Toray Co., Ltd., Kaneka Corporation, and Ube Corporation in Japan. Colorless polyimide (CPI) film is mainly used in flexible cover glass owing to its high light transmission, bending resistance, and friction resistance. The major suppliers of CPI are Kolon Industries Inc. in South Korea; DuPont and Nexolve in the USA; and Kaneka and Mitsubishi Gas Co., Ltd. in Japan.

In the field of adhesive polymer material (OCA), 3M Company in the USA and TESA Group in Germany have monopolized the high-end market, followed by enterprises in Japan, South Korea, and Taiwan, China. These companies control more than 80% of the whole market. With respect to optical clear resin, the main manufacturers include DuPont, Dow in the USA; SK Innovation in South Korea; and Kyoritsu Chemical-Check Lab., Corp. and Idemitsu Kosan Co., Ltd. in Japan.

The core constituent of photosensitive holographic recording polymer material is methyl methacrylate organic polymer (PQ/PMMA) doped with phenanthrenequinone, which is in strong demand in China. Major manufacturers include Mitsubishi, Sumitomo, and Arkema Group in France. Currently, Chinese companies are capable of producing optical PMMA, but the output is relatively small and imports are still necessary.

2.2 Development trends

Cutting-edge technologies and emerging market demands drive product diversification, industry concentration, and iterative acceleration. Influenced by the carbon peaking and carbon neutrality goals, environmentally friendly, intelligent, and digital advances have become the development characteristics of China's display industry, with increased localization of supply chains, industrial integration, and regional agglomeration. Display materials are expected to become thinner, purer, larger, and more composite-based in the future.

2.2.1 Thickness

The use of display materials that have small thickness values is not only a necessary condition for terminal portability and convenience but is also important for flexibility. For example, flexible glass that is applied to folding terminals has become thinner than 50 μm, with one-time molding and high toughness, while polarizers that are less than 70 μm have been developed.

2.2.2 Purity

The performance boost of display devices requires higher-purity materials such as OLED luminescent materials, targets, electronic gases, and rare-earth polishing materials.

2.2.3 Composite

With improvements in human–computer interaction and human-feeling experiences on terminals, high-performance display materials are needed to satisfy composite functions. For example, OCA optical adhesive is doped with other materials to have high stability, flexibility, and weather resistance; glass display material can have display and even protein analysis functions in the medical and health fields through component reconstruction, coordination, and reinforcement.

2.2.4 Size

The increasing pursuit by consumers of large-size displays has led to an increase in the size of display terminals. Meanwhile, such demands increase the requirements pertaining to the size of the glass substrates, photomasks, polarizers, etc.

3 Development status of China's key information display materials

3.1 Expanding market

China attaches great importance to the development of information display materials and has promulgated supportive policies that expand the domestic supply chain of key materials and equipment. It has issued a series of display industry-related policies such as the *Key Research and Development Plan for Information Display and Strategic Electronic Materials*, vigorously promoting the display industry and guiding the improvement of independent supporting capacity in the field of key materials and equipment. In 2020, the output value of display

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materials in China reached 13.759 billion USD (Table 2), and the industry scale increased by 30% compared with 2019, achieving a new high [13].

Table 2. Display industrial output value in mainland China (Unit: billion USD).

Type	2016	2017	2018	2019	2020
Panels	42.401	37.167	38.115	38.778	50.429
Materials	13.134	11.114	13.624	10.717	13.759
Equipment	1.0	1.0	1.0	1.0	0.7

3.2 Technological breakthrough

With an increase in the development of novel information technologies and industrial transformation, China has made significant progress on some of the key materials and techniques. For example, China's liquid crystal materials have been independent, and the local self-supply rate has reached 53.8%, among which the high-performance TFT hybrid liquid crystal product has been applied to downstream applications. High-purity molybdenum targets, copper targets, oxide semi-conductor sputtering targets, optical film, and OLED intermediate/front-end luminescent material have been localized. In addition, quantum dot photoluminescent materials and quantum dot backlight devices have been industrialized. The 4th to 8th generation photomask substrates are being manufactured, and the self-supply rates of electronic gases and wet electronic chemicals have reached 55% and 40%, respectively. High-generation liquid crystal glass substrates have witnessed breakthroughs, and foldable glass with a thickness of 30–70 μm has been mass-produced. The key technology employed in laser display machines has reached a leading international level, and the pilot-run verification test of micro-LED chips and CPI films has just begun.

3.3 Completing system

China has established the National New Display Technology Innovation Center, forming an enterprise-based, market-oriented industry–university–research system. Collaborative innovation has been conducted focusing on the industrial chain, steadily improving the technology and innovation level of the whole industry and gradually improving the weak links in key materials of the industrial chain. We have achieved international leadership in TFT-LCD technology. Frontier domains such as light field displays and nano-LED displays are keeping pace with developed countries. Photomasks, polarizers, and photoresists have been manufactured. The development of laser displays and micro-LED displays has reached a world-leading level.

4 Shortcomings

4.1 Weak industrial base

The problem of a weak industrial base is becoming apparent despite the progress made. Many core components, parts, and materials, as well as advanced manufacturing processes and equipment, even software and research and development (R&D) platforms, cannot be self-supplied and must be imported from developed countries.

Specifically, functional materials (e.g., OLED terminal luminescent materials and laser display fluorescent materials), glass materials (e.g., high-generation TFT-LCD glass substrates and OLED glass substrates), kitting materials (e.g., color photoresists and high-precision photomasks), and polymer materials (e.g., high-end PI films and flexible OCA optical adhesives) are heavily dependent on imports. The same is true for the OLED luminescent material sublimation purification technique, mini/micro-LED chip miniaturization and mass transfer technique, high-generation TFT-LCD glass substrate producing technique, photoresist resin and photo initiator producing technique, quartz substrate for high-end mask technique, and PI film biaxial stretching technology. In addition, the upstream key raw materials, including fluorescent materials for laser display, ultra-thin Invar for AMOLED FMM, polarizer PVA films, and TAC films, cannot be self-supplied.

4.2 Absence of high-level arrangement

Overall, China lacks high-level planning guidance as well as innovation-driven and industrial system-oriented development. Meanwhile, R&D into core technologies and high-end products is overly dependent on only a few large domestic enterprises. Innovation and funding in small- and medium-sized companies are insufficient, causing the industry to focus on low-end products. Among the key display materials, OLED terminal materials, high-end

ITO targets, high-generation TFT-LCD photoresists, photomasks, high-purity ammonia for the OLED process, wet electronic chemicals for OLED and high-generation TFT-LCD panels, high-performance PI film, and flexible OCA optical adhesive lack high-level coordination and proper R&D investment. This leads to severe restriction in terms of core technologies and intellectual property patents, posing a negative impact on the development of China's information display industry.

4.3 Low application rate of innovation achievements

The display material industry involves interdisciplinary disciplines such as physics, chemistry, mechanics, and optics. Research institutes and universities are facing a dilemma with respect to the application of technologies. On one hand, R&D of display materials is often subject to assessments of the requirements of paper and patents, while on the other, it mainly focuses on material structure and new functions while the real focus on the market pain point products in the research field is relatively lacking. For example, few studies have been conducted on condensed matter structure control, process control, product uniformity, and stability of high-performance PI film; however, these factors are crucial for product performance and quality. Moreover, related enterprises in China face various problems including inadequacy in effective investment in technological innovation and resources, unsustainability, dependence on imported key components, and lack of technical reserves. In general, there is a disconnection between original research breakthroughs and industrialization achievements in the field of display material in our country. The market conversation rate of our information display material innovation results is low.

5 Future paths of China's information display materials

5.1 Target

China needs to focus on the key problems of display materials in the core systems, major projects, and application systems to establish an efficient and coordinated regular management mechanism to improve its comprehensive planning ability, the level of core technology, and to achieve a modern industrial system. The technology and application of key industrial materials are expected to keep pace with international advanced levels.

By 2025, the industrial structure of key display materials will have been optimized; the product structure of basic materials will have been upgraded, and the self-supply rate will exceed 60%. Further, an innovation-led, market-oriented, coordinated, and environmentally friendly industrial system will be built to meet the major demands of the information display industry for display materials, and the overall level has reached the advanced international level. The level of third-party testing institutions in the field of display materials has been significantly improved in China and an evaluation system has been basically established. A material-based product quality evaluation system and a material production process quality control evaluation system have been formed.

By 2035, the information display material ecosystem will be complete and the entire supply chain will be self-sufficient. China will gain independence on key materials for the display industry. With respect to cutting-edge materials, China is expected to take the high ground and the display industry will be self-reliant.

5.2 Paths

5.2.1 Strengthening of weaknesses

It is suggested to take advantages of China's system and market and organize research institutes and production enterprises to jointly tackle the weaknesses of OLED luminescent materials, high-generation TFT-LCD substrate glass, photoresist, mask, high-purity ammonia for the OLED process, wet electronic chemicals for OLED and high-generation TFT-LCD panels, high-performance PI film, OCA optical adhesive, etc.

5.2.2 Focus on advanced materials

Suitable arrangements should be made to improve basic innovation capability, as well as the development of a research and development plan for cutting-edge technologies such as nano-LED displays and light-field displays. A successful industrial application is a guarantee for taking the high ground in international competition.

5.2.3 Completion of innovation system

By integrating innovation with application and strengthening interdisciplinary collaboration, an enterprise-based, market-oriented, government–industry–university–research–application harmonized innovation ecosystem can be built. Thus, the innovation and talent training platforms would be able to promote the construction of national information display material demonstration districts.

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5.2.4 Production of high-end products

For high-end materials, "quality manufacturing projects" should be launched, and companies should be encouraged to upgrade their products by introducing intelligent and environmentally friendly manufacturing technologies to be competitive in the high-end market.

5.2.5 Promotion of industrial coordination

According to the situation of the industry and downstream applications, display material industrial clusters are required. They facilitate coordination between chain-related industries, research institutes, manufacturers, colleges, service, and trade, as well as financial institutions.

5.2.6 Development of core equipment and smart hardware

It is necessary to implement a display material and equipment integration action by organizing related material production units, equipment development units, universities, and research institutes to jointly tackle key problems, accelerate the research, development, and application demonstration of core equipment and intelligent systems, and solve the dilemma that core equipment, instruments, and systems required for research, development, production, and testing of display materials cannot be produced independently and even face international embargo. Synchronization of hardware and software could enhance the ability to cope with unknown risks.

5.3 Breakthrough of key techniques

To achieve self-reliance in information display materials, core intellectual property must be mastered to gain a competitive edge by 2030. The following is an analysis and assessment of some key techniques.

OLED luminescent materials can be divided into three generations: fluorescent, phosphorescent, and thermally activated delayed fluorescence (TADF). Because of the efficiency limitations of fluorescent material, phosphorescence and TADF are expected to quickly become mainstream. Future research may involve basic theoretical research such as the phosphorescence material excited state theory and the reverse gap crossing process of TADF material energy; and applied techniques such as efficient utilization of heavy metals (e.g., iridium, platinum, and rhenium) for phosphorescent materials, and low color purity and efficiency roll-off problems in TADF material applications. In terms of process, high purity, single sublimation at a high rate, and continuous sublimation in the vacuum sublimation purification technology of OLED luminescent materials should be addressed.

In terms of glass substrate materials, first, basic research should be conducted on thermal engineering theory and numerical and physical simulation research of high-generation TFT-LCD glass substrates and high-strength cover glass. Second, high-strain-point aluminosilicate glass formulation, ultra-thin forming technology, glass clarification, and homogenization are important to make the industry larger, greener, and more efficient.

The OLED glass substrate float technique develops products with large size, high stability, and high production capacity. Carrying out R&D into precision molding, efficient melting, clarification and homogenization, and micro-stress and reheat shrinkage control technology for OLED glass substrates helps the relative thermal shrinkage ratio reach less than 10 ppm.

To achieve the self-supply of G6-or-higher FMM products for AMOLED, graphic design and high-precision requirements must be satisfied to overcome the material instability. In addition, research on hybrid electroforming and the etching process is critical.

With respect to the AMOLED targets, the manufacturing process of the large-scale integrated silver alloy targets should be realized by studying the key technologies of microstructure control (e.g., smelting and casting, plastic forming, and the recrystallization of large-scale silver alloy target blanks during construction and application). Through the doping of rare-earth elements, the carrier transport path of oxide semiconductor materials can be regulated and optimized, and high-mobility rare-earth-doped metal-oxide semiconductor targets can be manufactured.

With respect to acrylate-based OCA optical adhesives, reducing curing shrinkage, increasing refractive index and transmittance, increasing curing speed, enhancing stability, and greening diluents are the focus points. Researchers can also focus on stress defects due to volume shrinkage during curing and reduced volume shrinkage ratio control. Furthermore, the flexibility and processability of different types of adhesives can be improved by using appropriate additives. For example, the curing shrinkage can be reduced to less than 2.5%.

When studying high-performance polyimide materials for flexible displays, the manufacturing capability of high-transparency and high-temperature resistant polyimide material is critical for: (1) studying the influence of the monomer structure, slurry ratio, preparation process and conditions on material transparency and temperature resistance; (2) developing the mass production process for high temperature resistant transparent flexible display substrates; (3) making the average light transmittance of the high-temperature PI film at a thickness of 20 μm more than 88%, haze less than 0.2%, glass transition temperature higher than 460 °C, thermal expansion coefficient less than 5 ppm/°C (100–400 °C), and tensile strength greater than 300 MPa; and (4) studying the molecular design and controllable synthesis research of photosensitive polyimide photoresist materials to enable mass-production with a viscosity fluctuation of the slurry of less than 5% (freezing storage for 6 months), exposure of less than 300 mJ, and resolution of less than 3 μm.

6 Suggestions

6.1 Building a novel R&D platform

We propose that China's system be maximized by using the national industrial policy as a guide and leading enterprises as the core, bringing together universities and scientific research institutes, and establishing a cross-domain, large-scale collaboration, and high-intensity national-level new R&D platform based on the Yangtze River Delta and the Guangdong–Hong Kong–Macao Greater Bay Area. After exploring a new type of collaborative innovation system with strengthened interdisciplinary integration, basic and applied research should be conducted through major scientific and technological research projects, full-chain innovation collaboration, and a cross-field global collaborative R&D network. As a result, key common technologies and forward-looking technological applications will be tangible. Besides, technical talents will also help transform the industry from "single innovation" to "common innovation." Eventually, the whole platform will be the brain.

6.2 Planning major projects and upgrading technological systems

A flexible list should be made of the key material technologies that require further research, and related scientific arrangements must be made. First, the performance and market scale of materials (e.g., the 8.5th generation TFT glasses, target materials, and wet electronic chemicals) must be improved and increased to attract an international competitive advantage, although some of them can be self-supplied. Second, G10.5/11 generation LCD glass substrates, OLED luminescent materials, and photoresists are in urgent demand and have the potential risk of supply interruption. Therefore, domestic substitutes are required. Third, detailed R&D plans for materials related to cutting-edge display technologies, such as flexible display quantum dot materials, micro-LED display chips, and key materials for light field displays, should be developed. Overall, an R&D–production–reserve industrial technology innovation system should be made.

6.3 Cultivation of world-class enterprises and building of open capital platform

To win the fierce display material competition, a group of world-class enterprises with excellent products, outstanding brands, and leading innovations is needed, which can actively participate in global innovation alliances, financial market integration, and industrial structure reconstruction. We propose that the relevant state ministries and commissions formulate a catalog of advantageous benchmarking enterprises, strengthen special policy support for industry-leading enterprises, and support mergers and acquisitions to enhance the international competitiveness of major companies. The integration of capital marketization, an international open capital platform, and the interconnection of securities and funds in China and abroad will provide a good capital environment to achieve this goal. Thus, the high-level scientific and technological self-reliance of China's information display industry will be realized.

6.4 Integration of multichain and construction of industrial ecological system

First, leading enterprises are encouraged to take the lead in uniting enterprises at all stages of the industrial chain, universities, and institutes to: (1) establish a display material industry alliance, with ministries and commissions getting involved on a large scale; (2) establish an industrial collaboration platform; (3) promote the aggregation and effective operation of innovation resources, industrial resources, and capital resources; and (4) develop an interactive mechanism between industry demands and policies. Second, the point-to-point link between display materials and mid- and downstream panel/terminal enterprises should be strengthened. Special policies and "first batch" insurance compensation can effectively reduce the risks that have concerned companies. Third, it is proposed that there be improvements to the material public service system, an increased focus on material characterization capabilities, testing and evaluation methods, and standards systems, establishment of a big data

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center system for testing and evaluation, development of the Internet Plus testing and evaluation service mode, and an improvement in comprehensive industrial resource sharing services. In summary, "multi-chain integration" (innovation, industrial, capital, and policy chains) plays a pivotal role in constructing an industrial ecological system.

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